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Correlation of Moisture Content to Selected Mechanical Properties of Rice Grain Sample

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***Abstract*— The correlation between different levels of moisture content on rupture force at different grain orientation was determined for rice grain. Rupture forces of MR 220 CL2 variety rice grains under vertical and horizontal orientations were conducted in a compression test with an Instron 5500 Universal Testing Machine. It was found that the rupture force of rice at the horizontal orientation was higher than those at the vertical orientation for the entire range of moisture content. The correlation level of rice moisture content to rupture force of the grain were r = 0.933 and r = 0.924 for horizontal orientation and vertical orientation, respectively.**

***Keywords*— Moisture Content; Rupture Force; Grain Quality; Rice Grain.**

I. Introduction

Hardness is the resistance of the individual grain to deformation under applied forces [1-2]. Hardness is also defined as the ratio of the rupture force to the deformation at the rupture point of the grain [3]. Hardness could use as parameter that shows resistance of rupture due compressive force is given. Hardness measurements act by providing compressive force on the sample to the sample broken and destroyed.

Percentage presence of broken rice grains is an important quality criterion for the rice industry. The economic value of rice strongly depends on the presence of unbroken grains [4]. The mechanical properties of rice grain are important in the designing of machines for grinding, harvesting, milling, cleaning and separating of rice grains [1].

Rupture force is the minimum force needed to crack the individual grains [3]. If the compression exceeds the rupture strength of the material, it will lead to cracks or breakage. Several studies have been conducted on the physical and mechanical properties grains [2, 5-8].

Gupta [9] and Altuntas [10] claimed that rupture force decreased and rupture energy increased along with the increase of grain moisture content. Ogunjimi et al. [11] studied the mechanical properties of locust bean seed, which concluded that the seed orientation and grain thickness gave effect to resistance of grain for becoming cracked. The rupture force found in loading along the thickness lay was between 154 N and 204 N. Loading on the vertical axis gave the highest resistance to crack. Moreover, a similar study was done by Altuntas and Karadag [12] stated that the mechanical properties of sainfoin, grasspea, and bitter vetch seeds were determined by the average rupture force, specific deformation and rupture energy along X-, Y- and Z-axes. The mean values of rupture force, specific deformation and rupture energy for sainfoin seed were 7.40, 9.72 and 4.56 N; 8.94%, 1.71% and 9.97% and 1.97, 0.46 and 0.71 N mm for along X-, Y- and Z-axis, respectively. The mean values of rupture force, specific deformation and rupture energy for grasspea seed were 254.40, 42.60 and 100.80 N; 27.53%, 0.29% and 14.03%; and 187.20, 29.25 and 38.77 N mm for along X-, Y- and Z-axes, respectively. The mean values of rupture force, specific deformation and rupture energy for bitter vetch seed were 57.60, 45.00, 87.00 N; 7.60%, 1.62%, 1.93%; 10.14, 4.42, 0.86 N mm for along X-, Y- and Z-axes, respectively.

The effect of deformation rate and moisture content on the mechanical properties of rice grains were carried out many researchers [13-15]. Until to date, only few studies are available in the literature reporting on the rupture force of rice grains. The objective of this study was to determine the rupture force of rice grains at horizontal and vertical grain orientations.

II. Materials and Methods

Rice varieties MR 220 CL2 was obtained from the main rice cultivation area in Sungai Besar, Selangor. MR 220 CL2 is one of the new rice variety produced by the Malaysian Agricultural Research and Development Institute (MARDI). To determine the average size of the rice grain, a sample of hundred seeds were randomly selected. The three linear dimensions of the seeds, namely length (L), width (W) and thickness (T) were carefully measured using micrometer gauge with accuracy of 0.01 mm. The geometric mean diameter (GMD) and sphericity ratio were computed using the following equations [16].

$$GMD = (L*W*T)\ 1/3 \tag{1}$$

$$Sphericity = GMD / L \tag{2}$$

Where :

L = Length (mm)
W = Width (mm)
T = Thickness (mm)
GMD = Geometric mean diameter

The geometric mean diameter (GMD) and sphericity were used as parameter for physical properties of rice grain. Through knowing the moisture content, in this study was also determined the rupture force of the rice grain. Rupture force is one of the parameters in the mechanical properties. The experiments were conducted at loading rates of 3 mm per min. Quasi-static compression tests were performed using a compression test with Instron 5500 Universal Testing Machine (Fig. 1). For each treatment, 25 rice grains were randomly selected to measure the rupture force in different orientation (i.e vertical and horizontal orientation) with different moisture content.

A single grain was placed on the lower plate of the device, and the lower plate was then moved upward with a fixed speed of 3 mm/s, compressing the grain between two parallel plates until it fractured [17]. The load cell connected to the upper plate of the device converted the force applied to the single grain during compression into electronic signals, and then transferred the signals to a computer through a data acquisition board, recording the data on the computer for offline analyses. Loading was applied to each grain in two main directions, namely X-X and Y-Y load orientations (Fig. 2). The fixed loading speed of the device and elapsed time were used to determine the deformation that occurred during loading up to the rupture point for each individual grain [9].

In order to determine the effect of moisture content against rupture force, the grains were set in deferent moisture content with range of 10 to 30% in wet basis. The initial moisture content of the samples was determined by using grain moisture meter. The G-7 Delmhorst Grain Moisture Meter has moisture content range from 9 to 30%. It has built-in correction factors for various grains such as barley, coffee, corn, flax, hay, oats, rapeseed, rough rice, sorghum, soybeans, wheat, and rye. The grain meter has built-in temperature correction over the range of 0 to $37^{o}C$.

Rice grain samples were used directly after harvesting time in study area in Parit lima Timur Sungai Besar Selangor Malaysia. The moisture content for fresh rice grains was approximately 22% based on measurement by G7 grain moisture meter. To vary the moisture content of the rice grain was used two method, namely by soaking method and drying method. Moisture content increased with the increasing soaking time, while moisture content was decrease with increasing heating time.

Drying method was done using moisture analyzer M50. Moisture analyzer M50 is equipment that enables to determine moisture content inside rice. Fig. 3 shows moisture analyzer M50 during drying process. Grain moisture analyzer M 50 was set up with standard drying process $105^{o}C$. On the grain moisture analyzer screen was displayed the operation temperature, drying time, drying rate, and moisture content measurement. The drying processes for this research were done from 0 to 10 minutes inside the moisture analyzer. The different times drying process is used to get variation of moisture content until 10%. After drying process, rice put in desiccators for stabilization temperature inside rice before rupture test. Rice will put in the desiccant for one hour. Same with drying process, soaking method were done in 0 until 24 hours to increase moisture content until 30%.

Finally, after the time achieved, 25 grains were randomly selected to determine the rupture force using Instron 5500 Universal Testing Machine. The experiment conducted with 60 types different moisture content ranged from 10 to 30% at different orientation (i.e vertical and horizontal). The average value represented as the rapture force at certain moisture content for each vertical and horizontal orientation. Statistical analysis using Statistical Analysis System (SAS) software was conducted on the obtained test data.

Fig. 1. Instron 5500 Universal Testing Machine.

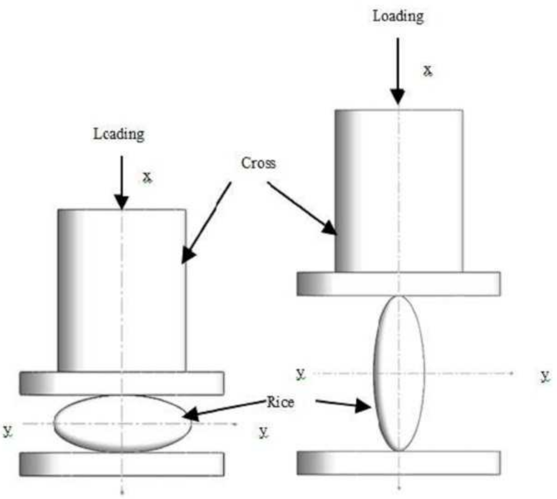

Fig. 2. Orientations of rice grain under compressive loading.

Fig. 3. MX-50 moisture analyzer.

III. Results and Discussion

Descriptive statistic on the dimensional sizes of the rice grains that were used in the tests are shown in Table 1. Geometric Mean Diameter (GMD) of the rice grain was 3.7759 mm with the standard deviation of 0.2883 mm. The rice grains used were almost of uniform size as indicated with the low coefficient variance of 7.63% for GMD and 8.04% for sphericity. However, sphericity of the rice grains was 0.3466 with the standard deviation of 0.0279. From this data, it showed that Rice varieties MR 220 CL2 were not having round shape, due to the sphericity value which was less than one.

TABLE I

Statistical analysis Geometric Mean Diameter (GMD) rice grain.

Parameter	GMD	Sphericity
Mean, mm	3.7759	0.3467
Median , mm	3.7504	0.3427
Standard Deviation	0.2884	0.0279
Range	2.8971	0.2650
Minimum, mm	3.5003	0.3182
Maximum, mm	6.3975	0.5832
Coefficient of variance (%)	7.63	8.04
Count	100	100

The relationship between rupture force and moisture content are as follows:

$$\text{Rupture force x-x} = -3.299X + 188.7 \quad \text{with } R^2 = 0.870 \qquad (3)$$

$$\text{Rupture force y-y} = -1.898X + 66.23 \quad \text{with } R^2 = 0.853 \qquad (4)$$

Where:

X = Moisture content (%)

The equation above was used to determine the rupture force based on moisture content. Correlation analysis results are shown as Pearson correlation coefficients (r). The rupture force values have high correlation with moisture content of rice grain with r = 0.933 and r = 0.924, respectively, for the X-X load orientation and for the Y-Y load orientation.

The measured rupture force from different moisture content was plotted against the moisture content in Fig. 4 and 5. Increasing grain moisture content from 10% to 29% would decrease grain rupture force from 156.05 N to 89.89 N and 56.74 N to 10.65 N in horizontal orientation (X-X axes) and vertical orientations (Y-Y axes) and horizontal orientation (X-X axes), respectively.

The results showed that the rupture force of rice grain decreased as the moisture content for both grain orientations increased (X-X and Y-Y load orientations). These findings highlighted that the value of grain rupture force at the horizontal orientation was higher than the vertical orientations. This value indicated that the material could be easily broken. This might be due to the fact that when the moisture content was high, then the grain would become softer and required less force. Dilday [18] mentioned that rice breakage decreased as rice moisture content increased within ranged from 12% to 26%.

Zareiforoush [15] studied on mechanical properties of two rice varieties under quasit-static compressive loading. The results showed that, for Alikazemi variety, the loading rates increased from 5 to 10 mm/min, therefore the force required for initiating the grains rupture decreased from 125.69 to 117.38 N and 33.51 to 29.94 N, respectively, at horizontal and vertical orientations. And for Hashemi variety, the grains rupture force decreased from 109.96 to 88.33 N and 25.39 to 21.68 N, respectively, at horizontal and vertical orientations with an increment in loading rates from 5 to 10 mm/min.

In horizontal orientation (Fig. 4), rupture force was 156.05 N at 10% moisture which was significantly more than force required initiating seed rupture at 29% moisture (around 1.7 times). However in vertical orientation (Fig. 5), rupture force was 56.74 N at 10.4 % moisture. This was significantly more than the force required to initiate seed rupture at 29% moisture (around 5 times). Hence the rupture forces at vertical grain orientation are 2.8 to 8.4 times greater than at vertical grain orientation. This might be due to the fact that at higher moisture content, the grain became softer and required less force. This conclusion was supported with the findings by Konak et al. [19], who reported that the highest rupture force of chick pea seeds was obtained as 210 N with a moisture content of 5.2% (dry basis). They also stated that the seeds became more sensitive to crack at higher moisture content; hence, they required less force to rupture. Altuntas and Yildiz [9] also conducted a research to study the effects of moisture content on some physical and mechanical properties of faba bean (Vicia faba L.). They reported that as the moisture content increased from 9.89% to 25.08%, the rupture force values ranged from 314.17 N to 185.10 N and 242.2 N to 205.56 N for X- and Y-orientations, respectively.

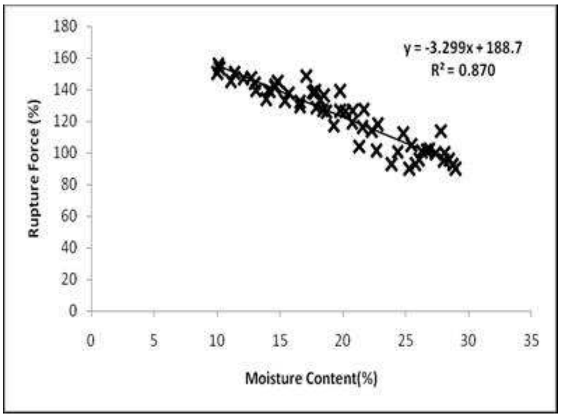

Fig. 4. Effect of moisture content on rapture force for rice in horizontal orientations (x-x orientation)

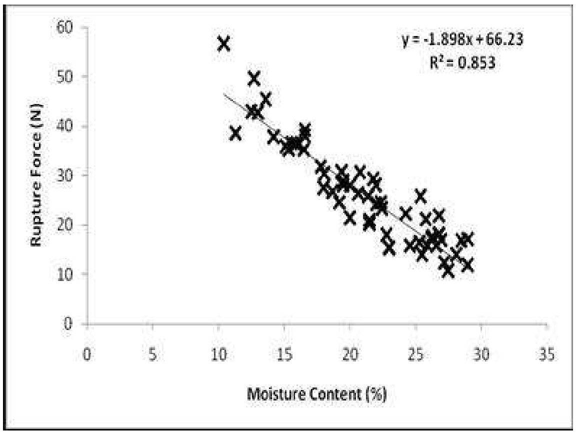

Fig. 5. Effect of moisture content on rapture force for rice in vertical orientations (y-y orientation)

IV. Conclusions

In conclusion, the rupture force has strong relationship with moisture content at both grain orientations. The rupture force grain in horizontal orientation is about 2.8 to 8.4 times greater than in vertical orientation. Rupture forces decreases from 156.05 N to 89.89 N and 56.74 N to 10.65 N in horizontal and vertical orientations respectively with increasing moisture content from 10% to 29%. The rupture force values of rice at the horizontal (X-X axis) orientation were higher than those at vertical (Y-Y axis) orientation in the entire range of moisture content. Rice grains at low moisture content conditions are less susceptibility to breakage losses during the post-handling and post-milling operations.

Nomenclature

L	Length	mm
W	Width	mm
T	Thickness	mm
GMD	Geometric Mean Diameter	

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